Coherent Lidar Design and Performance for Space Missions

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Results of Year 1

The performance of coherent Doppler lidar in the weak signal regime was determined from ground-based measurements supplied by Coherent Technologies, Inc (CTI) and compared with the results of computer simulations using the best velocity estimators. Good agreement was produced for one lidar pulse per velocity estimate and for estimates using 100 pulses of data. This demonstrates that pulse accumulation can increase the sensity and quality of space-based wind measurements. Using solid-state Doppler lidar data from CTI, mean tropospheric winds were measured up to an altitude of 6 km. in low backscatter regions. This provides useful information for scaling to space-based missions.

Improved algorithms for extracting the performance of velocity estimators with wind turbulence included were produced. Doppler lidar measurements of wind field statistics from CTI data were produced that are equivalent to point in situ measurements. This was accomplished by applying a correction for the effects of the spatial extent of the lidar pulse. The resulting wind field statistics are essential for evaluating Doppler lidar performance for the proposed scanning geometries of space-based missions. Simulations of the effects of refractive turbulence on laser propagation were also conducted in collaboration with Reg Hill of NOAA. This is particularly important for ground-based testing of lidar performance. Doppler lidar velocity estimation techniques were also applied to Doppler radar problems as a collaboration with Dick Strauch of NOAA.

Publications

"The use of state-of-the-art kites for profiling the lower atmosphere," B.B. Balsley, M. L. Jensen, and R. G. Frehlich, Boundary-Layer Meteorology, Vol. 87, 1-25, (1998).

"Coherent Doppler lidar measurements of wind field statistics," Rod Frehlich, Stephen M. Hannon, and Sammy W. Henderson, Boundary-Layer Meteorology, Vol. 86, 233-256, (1998).

"Evaluation of coherent Doppler lidar velocity estimators in non-stationary regimes," B. T. Lottman and R. G. Frehlich, Appl. Opt., Vol. 36, 7906-7918, (1998).

"Doppler weather radar velocity measurements using a single pulse", R. G. Strauch and R. Frehlich, J. Atmos. Ocean. Tech., Vol. 15, 804-808, (1998).

"Probability distribution of irradiance for the onset of strong scintillation," R. J. Hill and R. G. Frehlich, J. Opt. Soc. Am., Vol. 14, 1530-1540, (1997).

"Coherent Doppler lidar measurements of winds in the weak signal regime," Rod Frehlich, Stephen M. Hannon, and Sammy W. Henderson, Applied Optics, Vol. 36, 3491-3499, (1997).

"Evaluation of Doppler radar velocity estimators," B. T. Lottman and R. G. Frehlich, Radio Science, Vol. 32, 677-686, (1997).

"Effects of wind turbulence on coherent Doppler lidar performance", Rod Frehlich, J. Atmos. Ocean. Tech., Vol. 14, 54-75, (1997).

Results from Year 2

The performance of coherent Doppler lidar for a shuttle mission with various scanning geometries was determined using computer simulation which includes random instrumental velocity errors and also includes the effects of wind shear and wind variability along the range-gate and from shot-to-shot. The performance is defined by the probability density function (PDF) of the velocity estimates. The true radial velocity is defined as the average of the instantaneous radial velocity over the measurement volume described by the lidar shot pattern and range-gate length. For weak signals, the PDF is described by a localized distribution of good estimates and a uniform distribution of random outliers. For high signal levels there are only good estimates with no random outliers. The bias of the good estimates is negligible for all conditions. The fraction of outliers and the standard deviation of the good estimates were determined as a function of signal energy and the number of shots accumulated for each velocity estimate. For large pulse accumulation, the threshold signal level for acceptable estimates is proportional to the number of shots to the minus one half power. This agrees with previous results determined for ground-based measurements. The standard deviation of the good estimates depends on the wind variability but is typically less than 0.5 m/s when there are no outliers.

An improved maximum-likelihood velocity estimator was evaluated for space-based applications were signal shot measurements are used to produce vector wind measurements. This permits more accurate measurements when the signal level is not known a priori or not available from multiple shot measurements. New velocity estimators were developed for cloud interface regions. This includes variations in backscatter and velocity. Accurate measurements of the radial velocity is possible with small bias.

In situ atmospheric measurements were conducted using an instrumented kite-platform. This work is promising for providing the required in situ data for verification of Doppler lidar velocity statistics.

Publications

"The use of state-of-the-art kites for profiling the lower atmosphere," B.B. Balsley, M. L. Jensen, and R. G. Frehlich, Boundary-Layer Meteorology, Vol. 87, 1-25, (1998).

"Evaluation of coherent Doppler lidar velocity estimators for clouds," B. T. Lottman and R. G. Frehlich, Applied Optics, Vol. 37, 8297-8305, (1998).

"Atmospheric Measurements with Doppler Lidar and Instrumented Kite-Platforms", Rod Frehlich, Ben Balsley, Mike Jensen, Stephen Hannon, Sammy Henderson, and Phil Gatt, Battlespace Atmospherics Conference, San Diego, Jan., (1998).

"Maximum likelihood estimators for Doppler radar and lidar," R. G. Frehlich, J. Atmos. Ocean. Tech., Vol. 16, 1702-1709, (1999).

Results for Year 3

The performance of coherent Doppler lidar for a space missions with various scanning geometries was determined using computer simulation which contained the effects of random instrumental velocity errors, wind shear, wind variability along the range-gate and from shot-to-shot, and random variations in atmospheric aerosol backscatter over the measurement volume. The bias in the velocity estimates was small and the accuracy in the is typically less than 0.5 m/s for high signal conditions. For a large number of shot per velocity estimate, the threshold signal level for acceptable estimates is proportional to the number of shots to the minus one half power. This agrees with previous results determined for ground-based measurements.

The use of multi-element optical detectors for autonomous operation of coherent Doppler lidar was shown to be a very promising technique. Optimal detector geometries were determined by computer simulation of performance: for ground-based testing with a fixed calibration target and for space-based operation using the random surface returns.

The effects of refractive turbulence on ground-based calibration of coherent Doppler lidar was determined by computer simulations and compared with theoretical predictions. New techniques were required to correctly predict performance for the focused beam geometry commonly used for verification of space-based operation.

An improved velocity estimator was evaluated for space-based applications were signal shot measurements are used to produce vector wind measurements. This permits more accurate measurements when the signal level is not known a priori or not available from multiple shot measurements.

The average Doppler lidar signal spectrum including the effects of velocity turbulence was derived and calculated. This permits new estimation algorithms for turbulence based on spectral estimates.

Publications

"Coherent Doppler Lidar Signal Spectrum with Wind Turbulence", Rod Frehlich and Larry Cornman, Applied Optics, in press.

"Simulation of Laser Propagation in a Turbulent Atmosphere," R. G. Frehlich, Applied Optics, in press.

"Simulation of Coherent Doppler Lidar Performance for Space-Based Platforms", Rod Frehlich, J. Appl. Meteor., in press.

"Autonomous Beam Alignment for Coherent Doppler Lidar with Multielement Detectors," R. G. Frehlich, Applied Optics, Vol. 38, 6927-6941, (1999).

Inventions

A invention disclosure form number B9074 for an "Autonomous Coherent Doppler Lidar Receiver" was filed at the University of Colorado with Philip Gatt and Sammy Henderson of Coherent Technologies, Inc. as co-inventors. The review is pending.